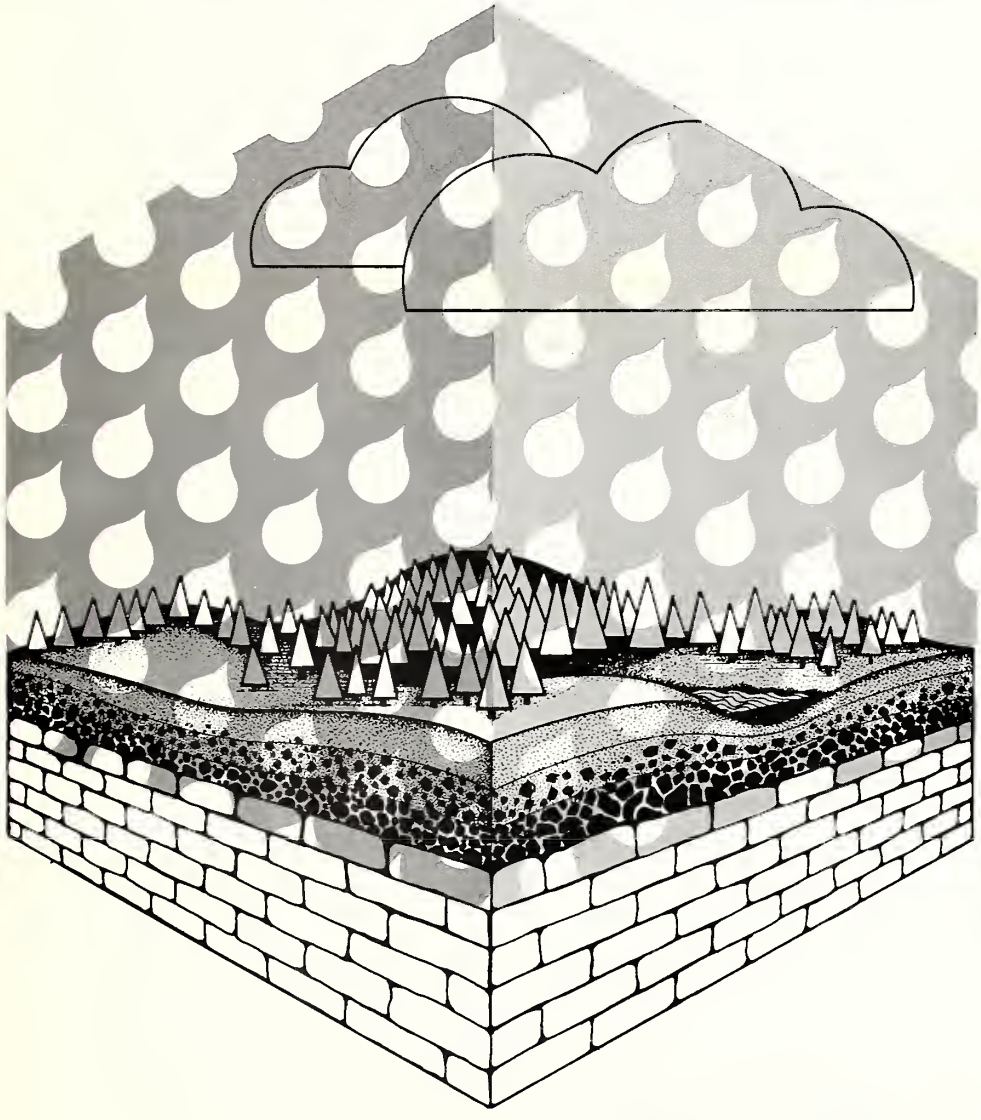
EARTH RESOURCES



MONOGRAPH 13

Forest Service/USDA
Region 5

LICHENS AND AIR POLLUTION IN THE SAN GABRIEL WILDERNESS, ANGELES NATIONAL FOREST, CALIFORNIA

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INTRODUCTION

Air pollution became a concern southern California during World War II when sulfur dioxide (SO_2) from petroleum production and other industries was the major component of the air pollution. In 1947 the Los Angeles County Air Pollution Control District was formed to control smoke and SO_2 emissions and to discover the chemical nature of a new type of pollution, smog. In the early 1950's smog was found to be composed of oxidant air pollutants including hydrocarbons and oxides of nitrogen (NO_x) that reacted with sunlight to form ozone. Oxidant air pollution levels rose sharply until approximately 1965.

While pollution levels in the South Coast Air Basin have dropped since 1965, the basin still exceeds federal and state ambient air quality standards for ozone, carbon monoxide, lead and total suspended particulates (TSP). The basin has the highest ozone and NO levels in the U.S with ozone exceeding the state standards 3.7 times and the federal standards 3.1 times. TSP, the pollution component primarily responsible for reduced visibility exceeded the state standards by 6 times. In 1980, the San Gabriel Mountains exceeded state standards of .10 ppm ozone 150 days and had an annual average of 8-10 ppm ozone (South Coast Air Quality Management Board 1982).

The Clean Air Act authorized the Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards to protect public health and welfare by preventing significant deterioration of air quality (Public Law 88-206 1977). In addition to establishing National Ambient Air Quality Standards, the Clean Air Act proclaimed all National Wilderness Areas and National Parks exceeding 5,000 acres that were in existence when the act was passed to be Class I areas. Federal Land Managers are required to "preserve, protect and enhance" air quality and air quality related values in Class I areas. Air quality related values include flora, fauna, soil, water, visibility, cultural/archeological and geologic features. Specific air quality related values vary between Class I areas.

The San Gabriel Wilderness is the only Class I area on the Angeles National Forest. While forest management activities do not contribute significantly to the long term air quality of the forest (Angeles National Forest LMP 1987), pollution originating in adjacent portions of the South Coast Air Basin moves into the surrounding San Gabriel and San Bernardino Mountain ranges with normal diurnal air flow patterns (Edinger et al. 1972). The EPA has established acceptable limits of deterioration for TSP, for visibility, and for physical levels of pollutants, but has not yet established acceptable limits of deterioration for vegetation (Sigal 1984).

The purpose of this project was to assess the effect of air pollution on the air quality related value of vegetation in the San Gabriel Wilderness by gathering baseline data on the current condition of the lichen flora of the wilderness and establishing a means of monitoring future changes. This was accomplished by collecting specimens, analyzing heavy metal content of selected specimens and establishing permanent plots and transects.

BACKGROUND

Vegetation damage resulting from pollution originating in the South Coast Air Basin has been documented since the 1950's in Ponderosa pine (Pinus ponderosa Laws.; Williams and Williams 1984), crops (Richards et al. 1958), bryophytes (Mishler 1979, Rao 1982), and lichens (Nash and Sigal 1979, Sigal and Nash 1983).

Lichens have been recognized as being sensitive to pollution since the late 19th century (DeWit 1983). Since that time many workers have used them as indicators of air quality in polluted areas throughout the world (see References Cited and Appendix G). Physical measurements of pollutants tend to be more accurate and less variable than biological estimates (Addison and Puckett 1980). However, biological monitoring can be beneficial where use of expensive monitoring equipment is not possible. In addition, when used in conjunction with physical monitoring, biological monitoring can provide data on the overall effects of air pollution in an area.

Fumigation experiments have demonstrated the effects of various pollutants in isolation of other factors. However, results from experimental fumigations are difficult to apply to natural conditions. Laboratory fumigations typically expose lichens to high concentrations of a single pollutant continuously for short durations in non-natural conditions (Sigal 1984). These artificial conditions can produce misleading results. Nash (1983) stresses the importance of realistic exposure, both in duration and pollutant concentrations. It should be noted that pollution effects on lichens are a function of pollutant concentrations, length of exposure, fumigation frequency, hydration state of the thallus and microhabitat characteristics, not only average levels of pollutant concentrations (Sigal 1984).

In general, pollution effects on lichens include

1. Mortality of sensitive species (DeWit 1983, Denison and Carpenter 1973, Kauppi 1983).

2. Decrease in thallus size (DeWit 1983, Kauppi 1983, Sigal and Nash 1983).

3. Decrease in fertility (Kauppi 1983, Sigal and Nash 1983).

4. Bleaching and convolution of the thallus (Sigal and Nash 1983).

5. Change in the ultrastructure of the thallus (Anderson and St.Clair 1983, Hale 1983, Holopainen 1984, Pearson 1985).

6. Altered photosynthesis and respiration rates (Rosentreter and Ahmadjian 1977).

7. Reduction in the number of algal cells in the thallus (Holopainen 1984).

8. Decrease in chlorophyll content (Kauppi 1983).

9. Elevation in content of heavy metals in the thallus (Addison and Puckett 1980; Carlberg, Drangsholt and Steinnes 1983; Gailey and Lloyd 1986a, 1986b, 1986c; Gough and Erdman 1977; Lawry 1986).

10. Decrease in pH (Kauppi 1983).

11. Restriction of lichen occurrence to the base of vegetation (Sigal and Nash 1983).

Most detailed knowledge exists on the effect of SO_2 on epiphytic lichens (Taylor and Bell 1983; Brown and Smirnoff 1978 in del Moral et al. 1984). Recently workers have studied the effects of ozone (Sigal and Taylor 1979), peroxyacetylnitrate (PAN; Nash and Sigal 1979), heavy metals (Farkas, Lokos and Verseghy 1985; Gailey and Lloyd 1986a, 1986b, 1986c, Garty and Fuchs 1982; Little and Martin 1974; Pilegaard 1979) and fluoride (Roberts and Thompson 1980). The documented effects of various pollutants are described below.

Oxidant Air Pollution. In higher plants ozone is thought to disrupt normal pathways of energy by altering cell membranes. No comparable data exists for lichens. Laboratory fumigation experiments aimed at determining the effects of ozone on lichens have produced contradictory results.

Rosentreter and Ahmadjian (1977) found that ozone fumigation resulted in a slight increase in chlorophyll content in Cladonia stellari at a concentration of 0.8 ppm. There were no visible morphological changes in lichen thalli at these concentrations of ozone. Chlorophyll content of isolated Trebouxia sp. algal cells grown on dry medium decreased while chlorophyll content of the same algae grown in liquid medium increased. While this study used "realistic" levels of ozone, the fumigation period was 1 week and was possibly too short in duration. In addition, they

used lower light levels when more damage is known to occur at higher light levels. Sigal and Taylor found that acute doses of high concentrations of oxidant air pollution increased photosynthesis rates in Parmelia sulcata and Hypogymnia enteromorpha. However 8 day fumigations at realistic ambient concentrations showed a marked decrease in photosynthesis rates in P. sulcata and slight and inconsistent decreases in H. enteromorpha. They concluded that Hypogymnia might require longer fumigation times to see significant reductions in photosynthesis rates. At the end of fumigations, Trebouxia algal cells from P. sulcata had a distinct yellow to brown cast. Algal cells from control material remained characteristically bright green. The central portion of most H. enteromorpha thalli turned brown, while the tips of the thalli remained unchanged.

Some lichens are damaged or killed at annual average NO_x concentrations of 3834-7866 micrograms/cubic meter (1.96-4.01 ppm). Total oxidant levels of .60 ppm or 1176 micrograms/cubic meter have been measured in the San Bernardino Mountains. Daily maximum hourly averages of PAN concentrations sufficient to cause injury to common herbaceous plants have also been measured (Sigal and Taylor 1979). Pollutant concentrations are not available for the San Gabriel Mountains. However, the annual average ozone concentrations in Azusa ranged between 0.11 ppm and 0.155 ppm between 1965 and 1980. These levels are higher than concentrations measured in San Bernardino. Ozone concentrations in the San Gabriel Wilderness can be assumed to have been higher than concentrations in Azusa. This is because ozone concentrations increase with distance from the pollution source as the oxides of nitrogen have had more time to react with sunlight (South Coast Air Quality Management District 1983).

Sigal and Nash (1983) correlated variation in species richness, frequency, cover and vitality with variation in oxidant air pollution levels in 5 southern California mountain ranges. From these studies they developed a scale with which to assess air quality based on occurrence and morphology of macrolichens (foliose and fruticose lichens). During three years of extensive collection of lichens in the mountains of southern California they found only 34 of the 91 macrolichens collected around the turn of the century by Hasse (1913). Eight of the 16 species of macrolichens previously located on three conifers (Abies concolor, Pinus jeffreyi, and Pinus ponderosa) in the San Bernardino and San Gabriel Mountains were still found. Only four of these eight were found in any abundance. They were Hypogymnia enteromorpha, Parmelia elegantula, the P. subolivacea complex (including Tuckermanopsis merrillii) and the Letharia vulpina complex.

Sulfur ioxide (SO_2). Some lichens are damaged or killed when annual average SO_2 levels are as low as 13 micrograms/cubic meter (.07 ppm). SO_2 effects on lichens are greater at lower pH

values. It has been found that SO_2 inhibits photosynthesis and respiration and increases potassium efflux. Algal cells are often affected as evidenced by discoloration; the thallus dies soon after algal cells are damaged (Wetmore 1985).

Galun, Garty and Ronen (1984) found that chlorophyll degradation correlated with increases in three different pollutants, but not with total SO_2 levels. In addition, Nieboer et al. (1979) demonstrated that SO_2 had more damaging effects when copper (Cu^{2+}) and lead (Pb^{2+}) ions were present. They argued that this phenomenon was due to the ability of SO_2 to reduce these elements to forms that can bond more strongly to receptor sites on the lichens.

Some vascular plants can show visible signs of pollution damage much sooner than will lichens. In SO_2 fumigation experiments, there was no observable change in the respiration, photosynthesis or CO_2 exchange rates of 56% of lichens exposed to 4-14 ppm-h. (ppm-h = pollution concentration x duration of exposure.) Many pine seedlings showed needle injury at levels as low as .5 ppm-h and kidney bean plants show depressed photosynthetic rates and doses of 1.1-1.8 ppm-h. In addition, many crop species such as spinach are extremely sensitive (Sigal 1984).

Heavy Metals. Heavy metal uptake by lichens can be accomplished by several means including extracellular ion exchange, extracellular electrolyte sorption, hydrolysis, and intracellular uptake (Nieboer et al. 1978). In addition, a large proportion of the elemental content of lichens is the result of particulate trapping within the interstitial spaces of the thallus. Surface morphology has been shown to affect this method of uptake (Nieboer and Kershaw 1983). Accumulated ion uptake has been found to be linearly correlated with amounts of ions measured in bulk precipitation (Pilegaard 1979).

The two main climatic influences on metal content are rain and wind. Retention of metals by cation exchange depends on moisture content of the thallus, pH of the rainwater (acidity increases the solubility of the metals), amount of rainfall (some rainfall is needed to hydrate the thallus but intense rainfall can leach some exchangeable metal content; Gailey et al. 1985). Wind is important in transporting pollutants from their source. Distance from the pollution source also influences heavy metal content of lichens (Puckett and Sang 1983).

All heavy metal contamination is not detrimental to lichens. Laboratory analysis indicates toxicity of heavy metals varies as follows: $Hg^{2+} > Ag^{+} > Cu^{2+} > Pb^{2+} > Co^{2+} > Ni^{2+}$ (Nieboer et al. 1979). Nieboer et al. (1979) also found that ions with ionic bonding properties, such as calcium, magnesium and potassium,

protected lichens against SO_2 damage while ions with covalent bonding characteristics did not.

Lead. The toxic effects of lead are well documented. Nieboer et al. (1979) and others found that lead affected cell wall permeability and caused potassium efflux. This potassium efflux also correlated with a decrease in carbon fixation.

Lead is primarily present as a solid (Lawrey 1986, SCAQMD 1983). However, it can also reach lichen thalli as an aerosol, particulate metal dryfall and acid rain. As a solid, it tends to settle close to roadways (Lawrey 1986, SCAQMD 1983). So lead has its greatest effects on lichens in the San Gabriel Wilderness in the latter three forms.

Zinc. Zinc has also been shown to cause damage to lichens. Rather than affecting cell wall permeability, this heavy metal affects chlorophyll. Galun, Garty and Ronen (1984) found that chlorophyll degradation increased as zinc levels rose. Zinc does not affect cell membranes because it forms weak bonds similar to those formed by calcium (Nieboer et al. 1979).

Copper. Nieboer et al. (1979) documented two phases of copper uptake in Umbilicaria muhlenbergii. During the first phase, copper ions bind to receptor sites on algal cells. During the second phase, copper ions bind to fungal cells as evidenced by potassium efflux (Nieboer et al. 1979). Nieboer et al. (1979 also determined that copper enhanced the effects of SO_2.

Other Minerals. In laboratory experiments nickel, cobalt and cadmium induced potassium efflux only in high concentrations. Mercury and silver were able to cause potassium efflux even in dilute concentrations (Nieboer et al. 1978).

The sensitivity of lichens to pollution may be attributed to a combination of factors as outlined below (Kauppi 1983):

1. Water and gas are exchanged over the whole surface of the plant.

2. Lichens can uptake, concentrate, and store many compounds in the thallus in concentrations higher than their surroundings.

3. Lichens are exposed to pollutants throughout the year and have no protective cuticle.

4. Lichens are slow in metabolic turnover and growth, thus preventing recovery.

5. Lichens are very long lived.

6. Lichens uptake minerals and water very rapidly.

Crustose lichens are considered to be less sensitive than are foliose lichens, which are considered less sensitive than fruticose lichens. The reasons for this differential susceptibility are not well understood and it most likely is the result of a combination of factors. The differences in sensitivity may be due in part to the fact that the thalli of crustose lichens are immersed in the substrate. This immersion buffers the pollution effects. This hypothesis is supported by data indicating that lichens of any growth form growing on substrates with low pH are likely to suffer less than those growing on more acidic substrates (Wetmore 1985, Ferry and Coppins 1979). In addition, foliose and fruticose lichens may suffer weakening of the thallus attachments which causes erosion of these lichen types (Sigal 1984).

While many workers cite the value of lichens in biomonitoring, most do not comment on the important role they play in ecosystems (Slack 1983). Lichens have long been known to be important as pioneers in soil formation and retention and in colonization of difficult habitats (Hale 1983, Slack 1983). More recently they have been shown to be important in mineral cycling and nitrogen fixation in ecosystems where they comprise a large percentage of the biomass such as sitka spruce forests (Nieboer et.al 1978, Pike 1978). The role of lichens in mineral cycling in other ecosystems requires further study (Sigal 1984).

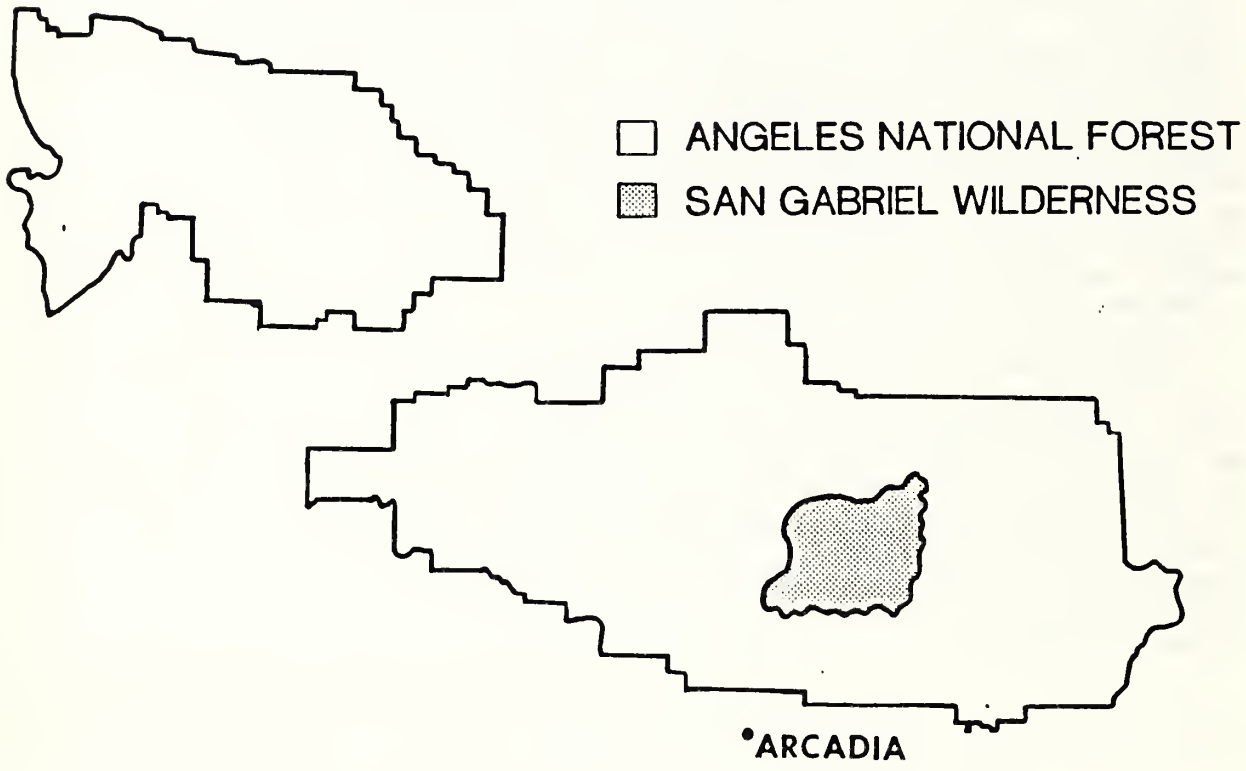
STUDY AREA

The San Gabriel Wilderness is a rugged 36,000 acre portion of the Angeles National Forest located in the San Gabriel Mountains (Figure 1). Elevations of the wilderness range between 1600 and 8200 feet. The elevational diversity is reflected in the vegetational diversity. Vegetation communities include soft chaparral and chamise chaparral (10,836 acres) mixed chaparral (16,253 acres), hardwood forest (2,528 acres) coniferous forest (1,643 acres), and big cone fir/hardwood association (3,052 acres).

The wilderness is bounded by ridges except at the southern border where Devils Canyon and Bear Creek drainages open into the West Fork of the San Gabriel River. Air pollution is funneled through these drainages from adjacent portions of the South Coast Air Basin.

This information was compiled from unpublished Angeles National Forest data.

Figure 1. Study Area: Angeles National Forest and the San Gabriel Wilderness. The San Gabriel Wilderness is the only Class I area on the Angeles National Forest.



METHODS

Field Work

I used three survey methods to assess the effect of air pollution on lichens in the San Gabriel Wilderness: floristic survey, chemical analysis and permanent plots on rocks and transects on trees. A discussion of various survey and monitoring methods is found in Appendix A.

Lichen distribution is greatly affected by substrate, aspect and fire history. Initially sampling sites were to be located stratified randomly throughout the San Gabriel Wilderness. However, preliminary surveys in and around the wilderness showed that lichens were extremely limited in distribution and were present only in isolated areas on north facing slopes and along drainages. To increase the chances of finding lichens, sampling was limited to north facing slopes which had not burned in at least 20 years. Sampling was further limited because steep terrain and/or thick vegetation limited access into some areas. I collected lichens wherever I found them but I established plots only at sites that could be relocated and sampled safely and efficiently. A sampling handbook was compiled to facilitate relocation and resampling of the plots.

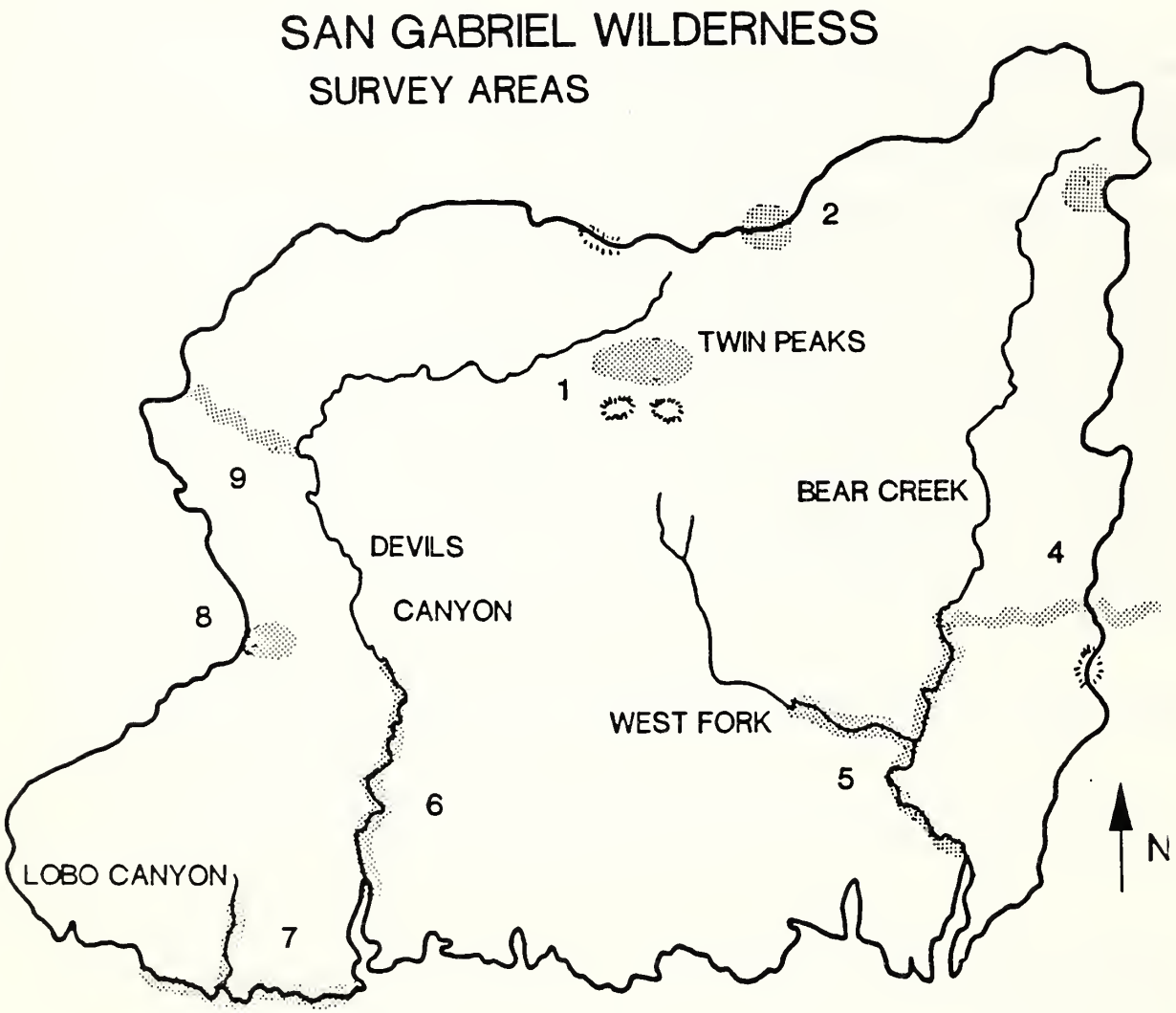
To locate potential sampling sites I mapped the fire history and vegetation types on 7.5 minute quadrangles. This information was compiled from unpublished Angeles National Forest data.

I selected 9 areas (Figure 2) that represented the elevational and vegetational diversity of wilderness while meeting aspect, fire and accessibility criteria.

AREA 1: Twin Peaks Saddle
VEGETATION TYPES: Mixed conifer.
ELEVATIONS: 6000-7700 feet
LEGAL DESCRIPTION: Waterman Quad T3N R10W Sections 27,28,29
ACCESS: Waterman Trail

AREA 2: Buckhorn Spring
VEGETATION TYPES: Mixed Conifer
ELEVATIONS: 7190-7000
LEGAL DESCRIPTION: Waterman Quad T3N R10W Section 15
ACCESS: Highway 2 past the Waterman Trail

Figure 2. Sampling site locations in the San Gabriel Wilderness.



AREA 3: Snow Spring
VEGETATION TYPES: Mixed chaparral; big cone fir/hardwood
ELEVATIONS: 4900-5800 feet
LEGAL DESCRIPTION: Waterman Quad T3N R9W Sections 18 and 19
ACCESS: Highway 39 above closure.

AREA 4: Bear Creek
VEGETATION TYPES: Soft chaparral; mixed chaparral; big cone fir/hardwood
ELEVATIONS: 2100-3900 feet
LEGAL DESCRIPTION: Crystal Lake and Waterman Quads T2N R10W Sections 11,12,16
ACCESS: Upper Bear Creek Trail

AREA 5: Lower Bear Creek, West Fork of Bear Creek
VEGETATION TYPES: Big cone fir/hardwood; riparian
ELEVATIONS: 2200-2390
LEGAL DESCRIPTION: Waterman Quad T2N R10W Section 11
ACCESS: Lower Bear Creek Trail

AREA 6: Devils Canyon
VEGETATION TYPES: Soft chaparral; mixed chaparral; big cone fir/hardwood
ELEVATIONS: 2500-3000 feet
LEGAL DESCRIPTION: Waterman Quad T2N R10W Sections 18, 19 13
ACCESS: Lower Devils Canyon

AREA 7: West Fork of the San Gabriel River, Lobo Canyon.
VEGETATION TYPES: Chaparral, riparian, big cone fir/hardwood
ELEVATIONS: 2400-2500
LEGAL DESCRIPTION: T2N R11W Sections 23 and 24
ACCESS: By boat through Cogswell Reservoir.

AREA 8: Ridge off of Highway 2
VEGETATION TYPES: Big cone fir/hardwood; mixed chaparral
ELEVATIONS: 5111-4900
LEGAL DESCRIPTION: Waterman Quad T2N R11W Section 1
ACCESS: Highway 2

AREA 9: Devils Canyon
VEGETATION TYPES: Big cone fir/hardwood, soft chaparral
ELEVATIONS: 4000-4800 feet
LEGAL DESCRIPTION: Chilao Flats and Waterman Quads T3N R11W Sections 25, 26, 36
ACCESS: Devils Canyon Trail

Floristic Survey

Each species of macrolichen found in the wilderness was noted and collected. Initially only macrolichens were to be collected but due to the lack of macrolichens, crustose lichens were also collected. Date, substrate, elevation, aspect, legal description, general location were recorded for each collection. These specimens were labelled and prepared for deposit in an herbarium. All specimens were identified using standard techniques such as chemical tests and spore examination when appropriate. I followed the taxonomy of Tucker and Jordan (1978). Charis C. Bratt of the Santa Barbara Museum of Natural History assisted with identifications.

I compared the species list I compiled with historical lists (Hasse 1913 and Sigal and Nash 1983) to determine whether the species composition of the flora had changed.

Morphological Comparison. I compared the general morphological appearance of my collections of Hypogymnia imshaugii, T. merrillii and Physcia stellaris with collections from areas in Santa Barbara and Kern Counties known to have relatively clean air.

Chemical Analysis

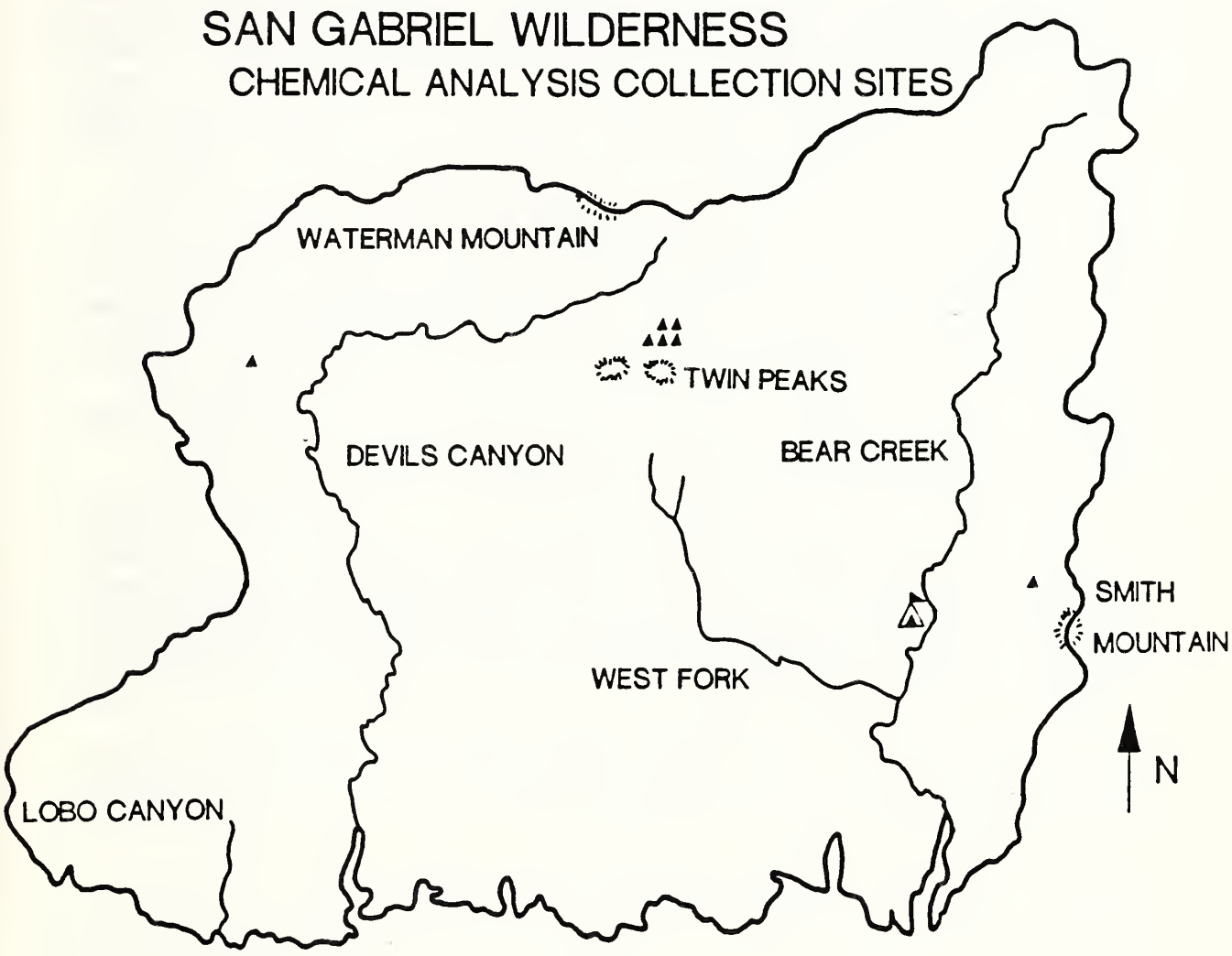
Samples of 7 lichens collected at various points in the wilderness were analyzed for chemical content (Figure 3). Levels of 27 heavy metals and minerals were assessed using optical emission spectrometry in the Laboratory of Biomedical and Environmental Sciences at UCLA.

Long Term Monitoring

I established permanent plots on granitic rocks and permanent transects on three species of trees. Transects on vegetation were preferred because lichens growing on bark are known to be more sensitive to air pollution than lichens growing on rocks (Hale 1983). All plots were marked with aluminum tags and the locations were mapped on 7.5 minute quadrangles. These maps, schematic drawings and verbal directions to each plot are included in the sampling handbook.

Data recorded at each plot and transect included date of sampling, general location (area), legal description, vegetation type, aspect, percent slope, elevation, substrate and directions to the next plot (compass heading and approximate distance, when appropriate).

Figure 3. Locations of the seven chemical analysis sampling sites in the San Gabriel Wilderness.



Vegetation Transects. Because the purpose of these transects was to monitor change in lichen cover over time, they were located in areas of high lichen cover. Due to the patchy and inconsistent distribution of lichens, no attempt was made to standardize the location of the transects on the trees. Because of this non-random location, the data collected this year are not representative of the amount of lichen cover in the wilderness as a whole.

Only live standing trees were used as plot trees. Each plot tree was marked with a numbered aluminum tag that was visible from the trail, or direction of access where no trail existed. Aluminum nails marked the beginning end of each transect. A measuring tape was secured the entire length of a transect so that it would not move during the measuring. Cover readings were always taken from the left side of the measuring tape which was lined up with the left edges of the two aluminum nails. The cover provided by each lichen species and by bark was recorded to the nearest millimeter. Initially, the number of millimeters occupied by each cover component was recorded on the data sheet. This changed to recording the ending position of each cover component. The actual distance occupied was calculated later.

In addition to the permanent transects, at each plot tree the approximate height to which Letharia vulpina cover extended vertically was measured using a clinometer. Percent cover was estimated visually. Only L. vulpina was measured using this technique because it was the only species of lichen that could be reliably seen at greater heights and it was the only lichen present on most plot trees.

Rock Plots. As with vegetation transects, rock plots were established where lichen cover was high. I specifically looked for high cover of foliose lichens.

In addition to aluminum tags, rock plots were marked with permanent paint in opposite corners of each plot. The dots I painted on the rocks were lined up with dots painted on the 30 x 30 plexi-glas plot guide. Fifty holes were randomly drilled into the plot guide. Everything occurring under one of these holes when the dots were lined up was recorded as 2 percent cover. Due to the difficulty of field identification, crusts were simply recorded according to their color and morphology (eg. black crust, gray crust, or brown crust) unless the were sufficiently distinctive to recognize in the field. For the same reason I did not distinguish species within the genera Physcia, Physconia or Xanthoparmelia.

Data Storage and Analysis

Floristic Survey

Collection information from the general collections was stored in a database using dBASE III+. Database fields included species name, elevation, substrate, aspect, general location, and legal description. The database can be queried on any of these fields to obtain information for many purposes.

Chemical Analysis

The results from the chemical analyses were entered into a dBASE III+ database that can be linked with the general collections database.

Long Term Monitoring

Data collected from plots and transects was stored and analyzed using LOTUS 1-2-3. Descriptive statistics were used to summarize the data.

Vegetation Transects. The total number of centimeters sampled, total number of centimeters occupied by bark, and the total number of centimeters occupied by each lichen species were calculated from the transects. Individual tree species were not analyzed separately because of the small sample size of each.

Descriptive statistics were calculated for total percent lichen cover. Total percent lichen cover on tree transects was calculated as

$$\frac{\text{\# of cm occupied by lichens}}{\text{\# of cm sampled}} \times 100$$

Percent cover of each species was calculated as

$$\frac{\text{\# of cm occupied by one species}}{\text{\# of cm sampled}} \times 100$$

Descriptive statistics were calculated for height and visual estimates of cover of L. vulpina for each transect tree.

Rock Plots. Total percent cover of lichen was calculated as

$$\text{total \# of holes occupied} \times 2$$

Percent cover of each lichen species or species group and bare rock was calculated as

# of holes occupied by each species/group x 2

Descriptive statistics were calculated for lichen cover on rocks.

RESULTS

Floristic Survey

I collected a total of 153 specimens between June 1 and August 29, 1987. One hundred eight collections were identified to 35 species. Twenty-seven collections were identifiable only to genus because specimens were infertile or because they did not fit existing keys. An additional 15 collections were completely unidentifiable for the same reasons (Table 1). A summary of frequency of collections and species by morphological type is presented in Table 2.

Areas 9 and 3 had the greatest diversity of species with 27 and 18 species respectively. The lowest diversity was found in Area 2 where no species were found (Table 3). Substrates observed to have lichen cover in the wilderness were big cone fir, canyon live oak, white fir, incense cedar and granitic rock (Table 4 and Figure 4). All collections were from north facing slopes.

Morphological Comparison. The H. imshaugii specimens I collected were extremely convoluted and bleached when compared with specimens collected in Santa Barbara and Kern Counties (Collections SG50, SG38, SG39 and SG48). Specimens of T. merrillii were void of apothecia (Collection SG130) or had large old apothecia but lacked young apothecia (Collection SG138). Specimens of T. merrillii were also small, convoluted and uncharacteristic of the species (Collections SG107, SG90 and SG42). In addition, one specimen of Physcia stellaris (Collection SG60) was void of apothecia and two other collections had very few apothecia (Collections SG69 and SG133).

Chemical Analysis

Lichen thalli were analyzed for content of 27 heavy metals the raw data appears in Appendix C. Chemical analysis showed that the samples contained high levels of silica, iron, and titanium. Mean levels and ranges of heavy metal concentrations are presented in Table 5.

Table 1. A list of species collected from the San Gabriel Wilderness including number of collections, substrate and locations.

SPECIES	NUMBER OF COLLECTIONS	SUBSTRATE	AREA
Acarospora chlorophana(?)	1	GR	3
Aspicilia sp. 1	1	GR	9
Aspicilia sp. 2	1	GR	8
Aspicilia sp. 3	1	GR	8
Aspicilia sp. 4	1	GR	3
cf. Aspicilia	1	GR	3
Buellia alboatra	2	WF/CLO	3
Buellia oidalea	1	CLO	3
Buellia sp.	2	GR/CLO	9
Caloplaca ulmorum	1	WF	3
Caloplaca sp.	1	CLO	9
Candelaria concolor	5	CLO/BCF	3,4,9
Candelaria concolor var. effusa	1	CLO	9
Candelariella cf. vittelina	1	GR	9
Candelariella sp.	2	GR	6,9
Catillaria globulosa	1	WF	1
Cladonia sp.	2	SOIL	4,9
Dermatocarpon miniatum	1	GR	4
Hypogymnia imshaugii	7	WF/GR	1,4
Lecanora mellia	2	GR	9
Lecanora muralis	1	GR	8
Lecanora pacifica	8	WF/CLO	1,3,9
Lecanora varia	3	WF/GR	1,3
Lecanora sp. 1	3	GR	3,8,9
Lecanora sp. 2	1	GR	8
cf. Lecanora	1	WF	3
Lepraria sp.	1	GR	9
Letharia columbiana	1	SP	1
Letharia vulpina	8	WF/BCF/IC	1,3,4,8,9
Melanelia sp.	1	GR	9
Peltigera canina	2	SOIL	4,6
Peltula sp. 1	2	GR	9
Peltula sp. 2	1	GR	9
Pertusaria amara	1	BCF	9

BCF = Big Cone Fir
CLO = Canyon Live Oak
WF = White Fir
S.PINE = Sugar Pine
GR = Granitic Rock
SOIL = Soil

Table 1. continued

SPECIES	NUMBER OF COLLECTIONS	SUBSTRATE	AREA
Physcia adglutinata	1	CLO	8
Physcia aipolia	1	CLO	9
Physcia albinea	2	GR	8,9
Physcia biziana	1	GR	8
Physcia callosa	5	CLO/GR	8,9
Physcia cf. callosa	4	CLO	4,5,9
Physcia stellaris	4	GR/CLO	3,6,8,9
Physconia detursa	2	GR	8,9
Physconia enteroxantha	7	GR/CLO	3,8,9
Psora sp. 1	2	GR	9
Psora sp. 2	1	GR	3
Rinodina sophodes	1	WF	3,9
Rinodina sp. 1	3	GR	3,4
Rinodina sp. 2	1	CLO	5
Sphinctrina leucopoda	1	CLO	1,3,8,9
Tuckermanopsis merrillii	14	CLO/GR/WF	3,8,9
Umbilicaria phaea	7	GR	
Xanthoparmelia cumberlandia	2	GR	6,9
X. kurokawae	1	BCF	8
X. mexicana	4	GR	3,8,9
X. novomexicana	3	GR	8,9
X. taractica	2	GR	4,5
Infertile Crusts	11	GR	1,4,8,9
Unidentified foliose	4	CLO/BCF	3,8,9

BCF = Big Cone Fir
CLO = Canyon Live Oak
WF = White Fir
S.PINE = Sugar Pine
GR = Granitic Rock
SOIL = Soil

Table 2. Summary of collections by morphological type.

MORPHOLOGICAL TYPE	NUMBER OF COLLECTIONS	NUMBER OF SPECIES
Crustose	62	42
Foliose	81	27
Fruticose	9	2
Imperfect	1	1

Table 3. Summary of collections by Area.

AREA	NUMBER OF COLLECTIONS	NUMBER OF SPECIES
1	19	8
2*	0	0
3	25	20
4	14	8
5	3	2
6	4	3
7*	1	0
8	29	20
9	57	32

* Areas were surveyed before crustose lichens were collected.

Table 4. Summary of collections by substrate.

SUBSTRATE	NUMBER OF COLLECTIONS	NUMBER OF SPECIES
Granite	68	47
Canyon Live Oak	44	18
White Fir	23	9
Big Cone Fir	10	6
Soil	4	2
Incense Cedar	2	1
Sugar Pine	1	1

Figure 4. Summary of occurrence of species by substrate.

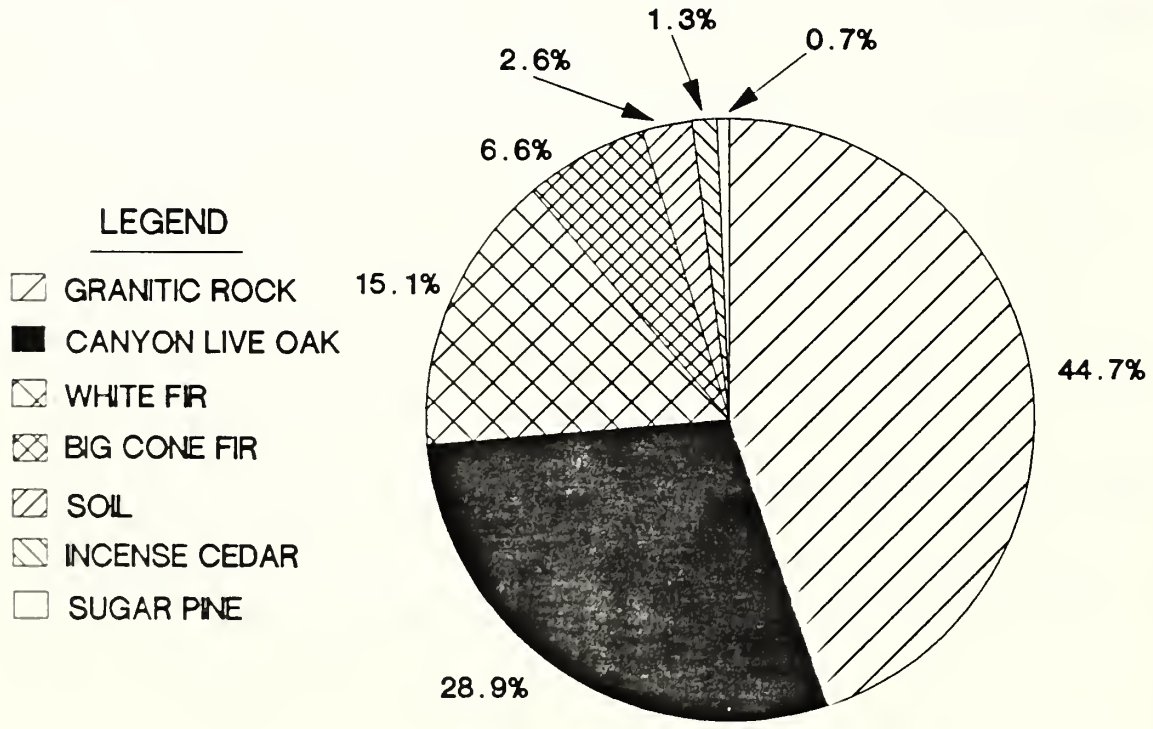


Table 5. Mean metal content of seven lichen samples collected in the San Gabriel Wilderness. All measurements are in ppm dry weight. Status was determined through comparison with Nieboer et al. (1978).

POLLUTANT	AVERAGE	RANGE	STATUS
Lead	78.55	2.99-114	Upper end unenhanced
Zinc	38.9	15.7-89.4	Unenhanced
Potassium	9380.5	4290-15,600	Enhanced
Aluminum	1289.6	156-2600	Enhanced
Titanium	46.72	3.27-101	Unenhanced
Vanadium	1.01	0-6.92	Unenhanced
Cadmium	13.26	0-2.66	Unenhanced
Copper	11.07	3.26-27.1	Unenhanced
Iron	1672.0	155-3700	Enhanced
Silicon	5980	1950-11900	Enhanced
Phosphorous	427	0-3340	Unenhanced
Sodium	900	87.0-2890	Unenhanced
Calcium	2952	351-24500	Unenhanced
Magnesium	1426	380-3330	Unenhanced
Manganese	140.5	47-355	Upper end unenhanced
Boron	2.8	1.14-4.67	Not Available
Cobalt	.53	0-1.20	Not Available
Nickel	.96	0-2.60	Unenhanced
Molybdenum	.92	0-2.41	Unenhanced
Chromium	2.32	0-9.47	Unenhanced
Strontium	22.8	1.91-57.6	Enhanced
Barium	35.3	10.4-75.6	Not Available
Lithium	1.98	0-3.7	Not Available
Silver	.01	0-.06	Not Available
Tin	.19	0-1.85	Not Available
Beryllium	0	0	Not Available
Arsenic	0	0	Not Available

Long Term Monitoring

Vegetation Transects. A total of 21 transects were established on trees; 8 were on big cone fir (Pseudotsuga macrocarpa), 9 were on white fir (Abies concolor) and 4 were on incense cedar (Calocedrus decurrens). Only three areas, Area 1, Area 4 and Area 9 (Figure 2) had trees with sufficient lichen cover to establish transects.

Thirteen transects were located in mixed conifer forests and 8 were located in big cone fir hardwood associations. Aspects at plots ranged between 325° and 21° true. Slopes ranged between 45% and 85% and averaged 66%.

A total of 1303.3 cm were sampled; 429.5 cm (33.0%) were covered with lichen while 873.8 cm (67.0%) were bark. Four species of lichen and one species of moss were found on the transects. L. vulpina was the most common lichen, covering 411.30 cm (31.6%). Lecanora pacifica occupied 7.4 cm (.6%), Candelaria concolor, occupied .55 cm (.04%), H. imshaugii occupied .6 cm (.05%), Grimmia sp., a species of moss, occupied 9.66 cm (7.4%) on one transect. Percent cover of lichen along individual transects ranged between 14.3% and 85.1% and averaged 33.2%. Sixteen of the 21 transects (72%) had less than 40% cover (Figure 5). Letharia vulpina comprised 96% of the lichen cover.

The height and percent cover of Letharia vulpina were recorded on 22 trees, the 21 plot trees and one additional incense cedar located in mixed conifer forest. The height of L. vulpina cover on trees ranged between .25 meters and 15.2 meters, averaging 7.36 meters, 13 out of 22 trees (59%) had cover only below 4 meters, (Figure 6). Visual estimates of percent cover of L. vulpina ranged between 5% and 40% averaging 15.23%. Twelve out of 22 trees (55%) had 10% or less cover (Figure 7).

Rock Plots. Percent cover of lichen in plots on granite ranged between 10% and 94% and averaged 72.1% (Figure 8). Twelve (80%) of the 15 plots had at least 80% cover. Total percent cover of individual species or species groups is summarized in Table 6. The most common lichens were black and brown crusts. Percent cover of foliose lichens in plots ranged between 4% and 70% and averaged 34% (Figure 9). The most common foliose lichens were four species of Xanthoparmelia, two species of Physcia and two species of Physconia. Individual species of these genera were not distinguished in the field.

Figure 5. Percent cover of lichens on transects on conifers in the San Gabriel Wilderness.

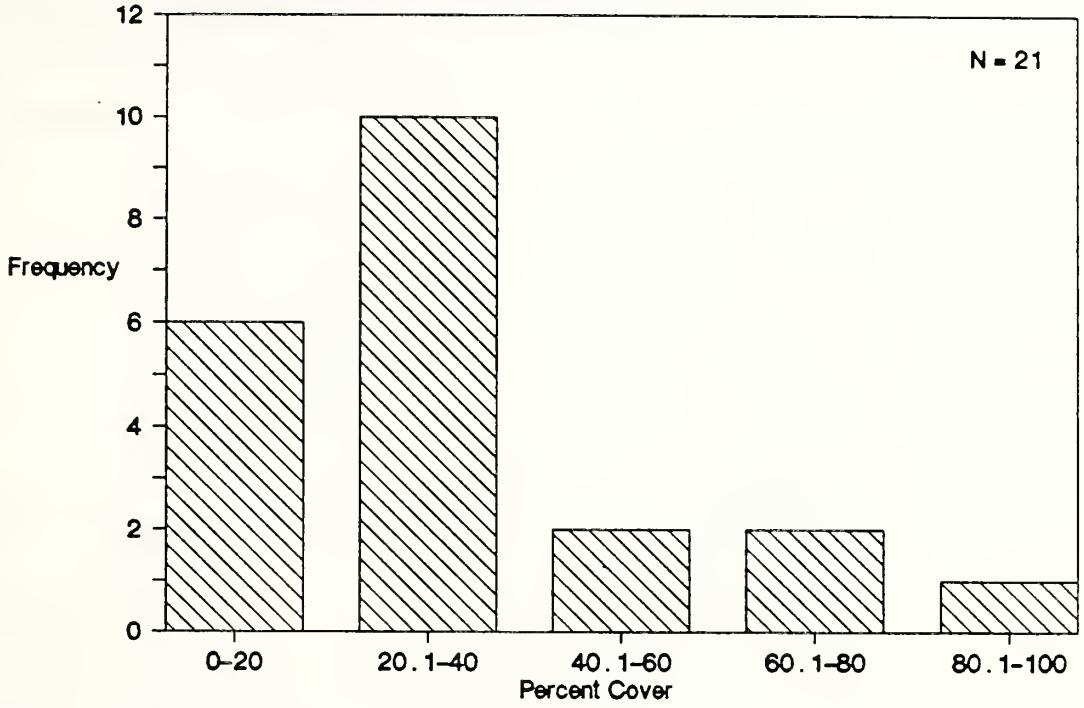


Figure 6. Height of lichen cover on the boles of conifers in the San Gabriel Wilderness.

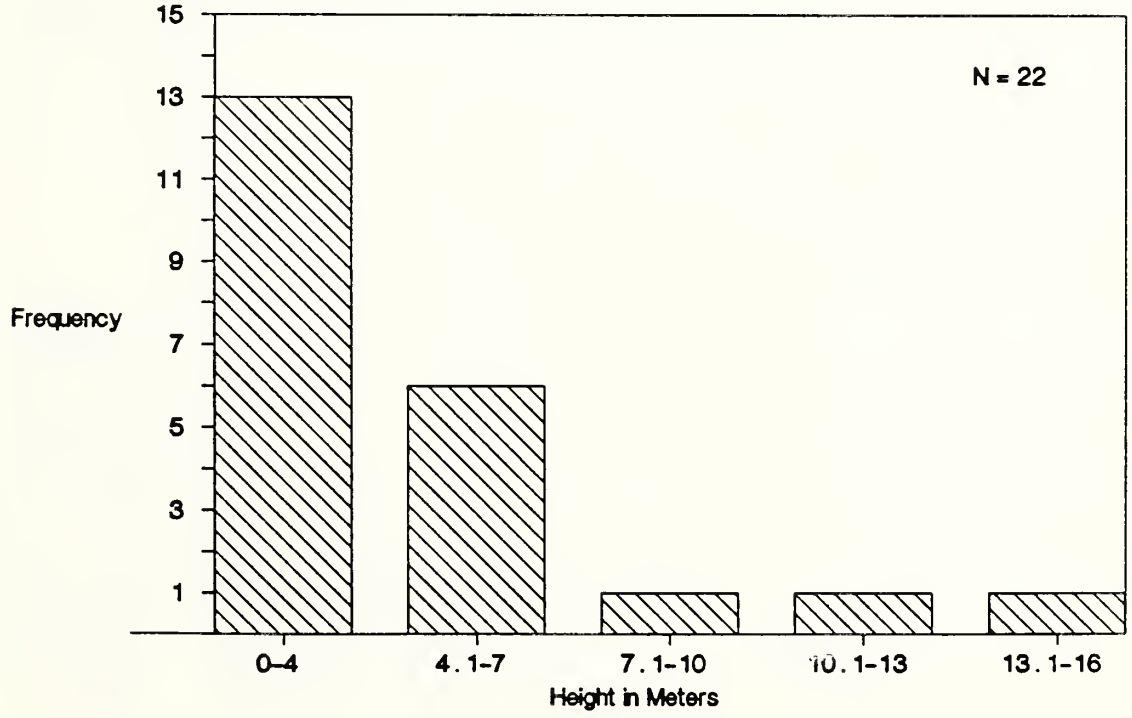


Figure 7. Visual estimates of percent cover of lichens on boles of conifers in the San Gabriel Wilderness.

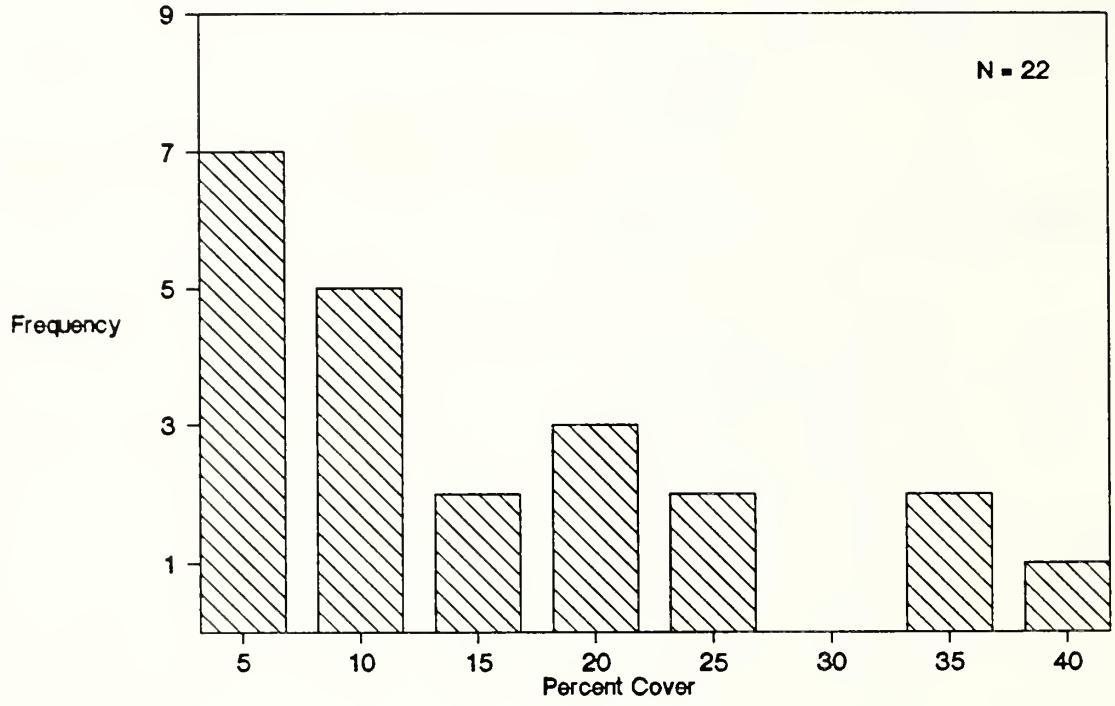


Figure 8. Total percent cover of all lichen on granitic rocks.

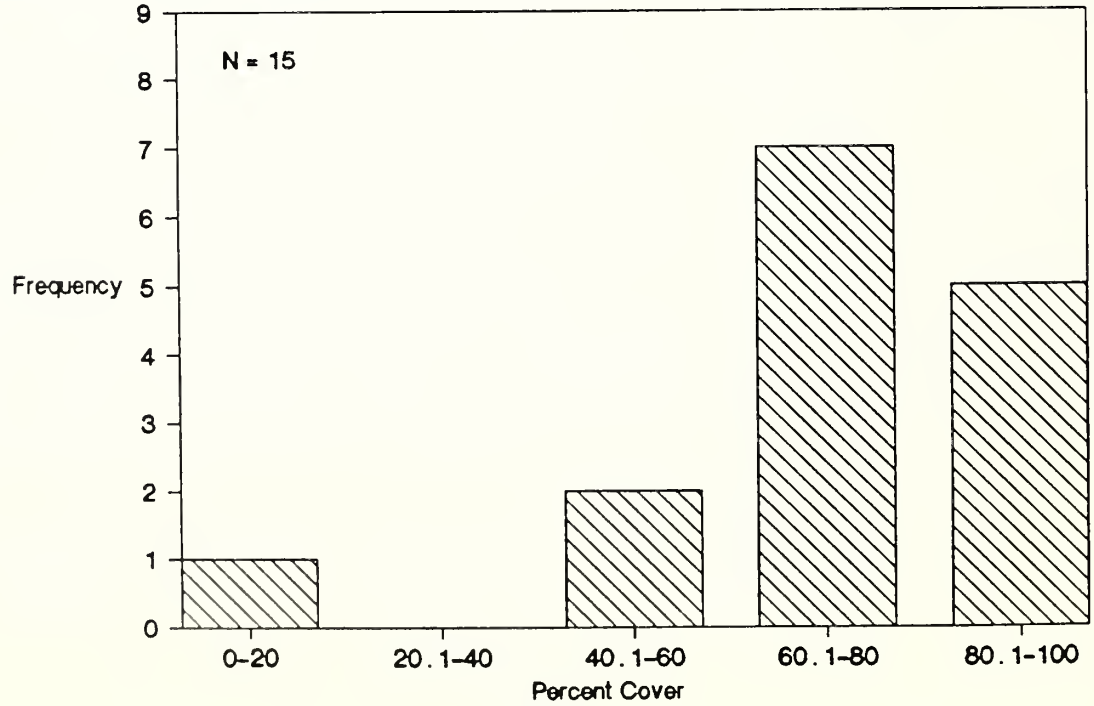
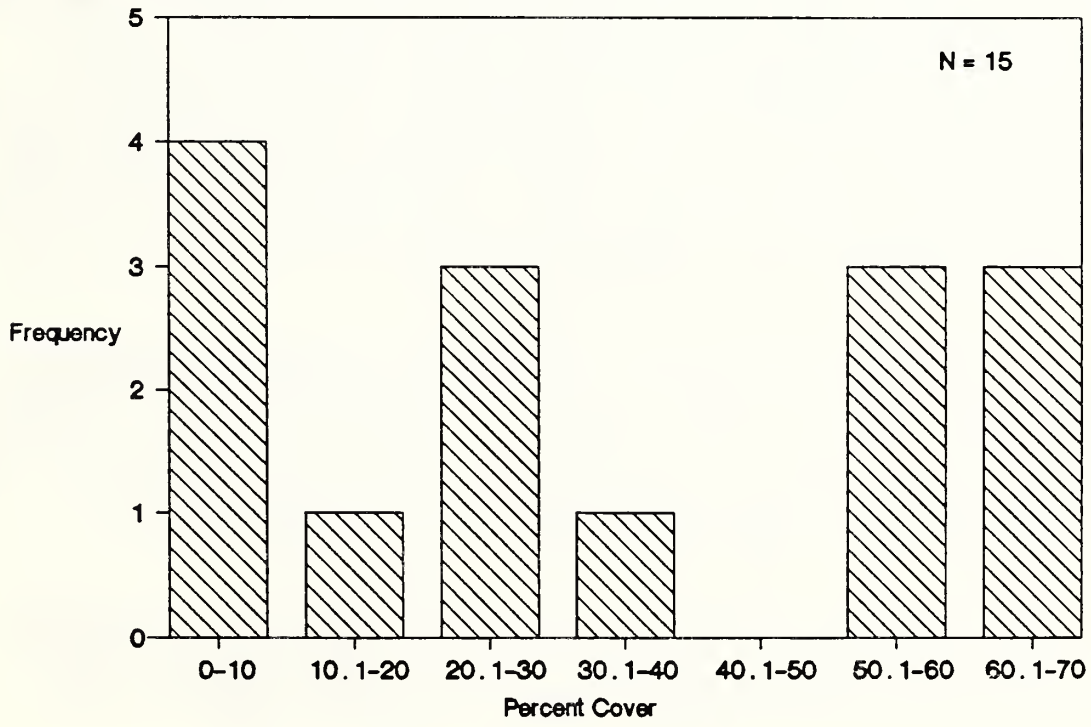


Table 6. Total percent cover of species or species groups found in rock plots. N=15.

SPECIES/GROUP	PERCENT COVER
Xanthoparmelia sp.	27.00
Grey Crust	27.00
Brown Crust	7.90
Umbilicaria phaea	4.00
Physcia sp.	3.40
Lecanora mellia	1.35
Black Crust	.94
Gold Crust	.81
Moss	.81
Tuckermanopsis merrillii	.40

Figure 9. Percent cover of foliose lichens on granitic rocks.



DISCUSSION

Floristic Survey

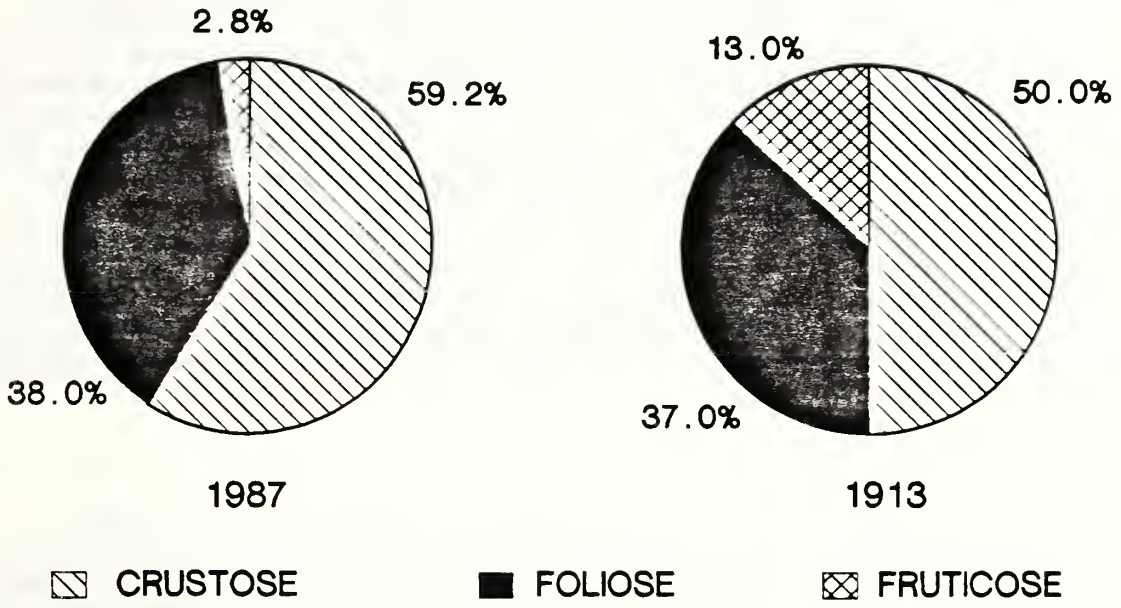
I collected 72 species in this study compared to 69 species collected by Hasse (1913). While the number of species is approximately the same, most lichens considered sensitive to air pollution that were once collected in the San Gabriel Mountains are now absent. The percentage of the flora comprised by fruticose lichens dropped from 13% prior to 1913 to 2.8% (Figure 10). I collected one lichen known to be very sensitive (Peltigera canina), one lichen known to be sensitive (T. merrillii), one lichen known to be moderately tolerant (H. imshaugii) and several species known to be tolerant (L. vulpina complex and the Physcia biziana group). In total, twelve species known to be very sensitive, and eight species known to be sensitive to oxidant air pollution are no longer found (Sigal and Nash 1983). Very sensitive species such as Ramalina menziesii that was once collected from oak trees along the Mt. Wilson Trail and Evernia prunastri that used to be "quite common in southern California" (Hasse 1913) are absent. The very sensitive species I collected was a soil lichen, the ability of soil substrates to buffer pollution effects is documented (Kauppi 1983).

Comparisons with Hasse's flora (1913) must be interpreted with care. First, a thorough lichen flora requires many years to compile. Thus, the lichens collected and documented during this study represent the more common, or more easily seen lichens occurring in the San Gabriel Wilderness. Undoubtedly, more crustose lichen species, and more uncommon species would be found with a more extensive search. In addition, it is not known how thoroughly Hasse (1913) collected in the San Gabriel Mountains. When selecting lichens from Hasse's flora (1913) for comparison, I counted only lichens specifically mentioned as occurring in the San Gabriel Mountains. Many more lichens may have been present at that time than were documented by Hasse.

Sigal and Taylor (1979) reported finding H. enteromorpha in the San Bernardino Mountains, but indicated that it was absent from the San Gabriel Mountains. I identified a similar species, H. imshaugii, that was not reported by Sigal and Taylor (1979) or Sigal and Nash (1983). Interestingly, I have been unable to find H. enteromorpha during casual collecting in either the San Bernardino or San Gabriel Mountains. All collections of Hypogymnia I have found are clearly H. imshaugii.

During a similar study in Sequoia National Park, Wetmore (1985) also found that L. vulpina and H. imshaugii were two of the three most common species. Wetmore (1983) did not find evidence of pollution damage by SO_2, ozone, or PAN.

Figure 10. Comparison of frequency of morphological types found in the San Gabriel Mountains in 1913 and in the San Gabriel Wilderness in 1987.



Of the species known to be sensitive to SO_2 (Wetmore 1985), Candelaria concolor was the only one found in the San Gabriel Wilderness. This is compared with eight SO_2 sensitive species collected in Sequoia National Park.

Morphological Comparison. Many specimens collected in the San Gabriel Wilderness exhibited symptoms characteristic of pollution damage. The degree of bleaching and convolutedness of H. imshaugii thalli resembled photographs of specimens of H. enteromorpha considered to be extremely affected by pollution by Sigal and Nash (1983). Many specimens I collected were hard for Charis C. Bratt to recognize and many did not fit existing keys. In addition 11 (17%) of the crustose collections were infertile. Several of these had apothecia but had not produced spores.

One of the dependable characteristics of Physcia stellaris is that it always has apothecia (Bratt pers. comm. 1987). Collections from the San Gabriel Wilderness had no, or very few apothecia. Collections of T. merrillii had large old apothecia, but had no young ones.

Chemical Analysis

High levels of silicon, iron and titanium in collections from the San Gabriel Wilderness indicate that they came from dusty areas. Unfortunately, the high iron levels prevented the analysis equipment from detecting levels of other elements, especially cobalt and phosphorous. Therefore, the low readings for cobalt and phosphorous are not valid (Rundel pers. comm. 1987). The high degree of variability within samples was most likely due to inhomogeneity of the samples and does not reflect biological or environmental diversity (Romney 1987 pers. comm.). Heavy metals are discussed below to the extent that information was available in the literature.

Lead. In unpolluted areas, lead concentrations of 5.2-100 ppm have been documented. Concentrations between 100 and 12,000 ppm have been recorded in polluted areas. Lead concentrations in lichens collected in the San Gabriel Wilderness are at the border between high background concentrations from unpolluted areas and low enhanced concentrations from polluted areas (Table 5; Nieboer et al. 1978). San Gabriel Wilderness lichens had a higher average lead content than the same species of lichens collected in Sequoia and Kings Canyon National Parks which averaged between 0.2 and 21.5 ppm (Wetmore 1985). It is clear that some lead pollution has affected the lichens in the San Gabriel Wilderness.

Zinc. In unpolluted areas zinc concentrations of 20-500 ppm have been documented. In polluted areas, concentrations between 100 and 25,000 ppm have been found. Damage is known to occur at concentrations of 200-600 ppm (Nieboer et al. 1978). The levels

of zinc in San Gabriel Wilderness lichens were comparable to levels found in unpolluted areas and were well below levels known to cause damage to lichens. San Gabriel Wilderness lichens had slightly higher zinc concentrations than lichens collected in Sequoia and Kings Canyon National Parks (Wetmore 1985).

Copper. In unpolluted areas copper concentrations of 1-50 ppm have been documented. Concentrations of 15-1100 ppm have been found in polluted areas (Nieboer et al. 1978). Copper concentrations from San Gabriel Wilderness lichens averaged 11.07% and probably reflect background concentrations.

Almost all heavy metal concentrations are comparable to concentrations found in unpolluted areas. It appears overall that heavy metals to not comprise a large portion of the pollution reaching the San Gabriel Wilderness. However, most average heavy metal contents were higher in lichens collected in the San Gabriel Wilderness than they were in the same species of lichens collected in Sequoia and Kings Canyon National Parks.

Long Term Monitoring

Vegetation Transects. The percent cover recorded on the transects is low considering that transects were located only in areas of high lichen density. Even with the biased locations, total percent cover for centimeters sampled was 32.5% and on individual transects cover averaged 33.2%.

Species known to be sensitive to pollution were absent from all transects (Sigal and Nash 1983, Wetmore 1985). A moderately sensitive species, H. imshaugii comprised 1.3% cover on one transect only and comprised .05% of the total 1303.30 centimeters sampled. The extremely tolerant L. vulpina was the dominant lichen, comprising 31.6% of the 1303.3 cm sampled.

The three dominant lichens on transects in the San Bernardino Mountains established by Sigal and Nash (1983) were L. vulpina, H. enteromorpha, and Cetraria merrillii (= Tuckermanopsis merrillii). Cover values of these three common lichens were high when oxidant doses were below 600 mg x h/m^3. Above this level C. merrillii was absent. In randomly located transects at breast height on white fir (Abies concolor) L. vulpina averaged 1.9% cover and H. enteromorpha averaged .01% cover. These cover values for L. vulpina are lower than values obtained during the present study due to the fact that transects in the present study were purposely located in areas with high lichen cover. While cover values were comparable for H. enteromorpha and H. imshaugii, H. enteromorpha occurred more frequently on transects in the study by Sigal and Nash (1983). In both studies Hypogymnia was more common off of the transects on the upper trunks and branches of trees.

While the line intercept method can be used to monitor changes in cover and species diversity over time, it lends itself to a great deal of sampling error. Therefore I feel it is reliable only for indicating large scale changes. In this study transects will not provide much information on reduction of species diversity because the flora is already depauperate. One species, L. vulpina, provided 96% of the lichen cover on transects.

The height to which lichens occurred on the bole of trees was low. One of the documented effects of air pollution is the reduction of lichen cover to the base of trees (Sigal and Nash 1983). Pollution may be influencing the restricted occurrence observed in the San Gabriel Wilderness, however without any historical data for comparison, there is no way to know if the height to which lichens occur has decreased. Because the transect trees were permanently marked, this height can be re-measured in the future to establish the presence of a trend towards increasingly restricted height.

Rock Plots. Total percent cover and percent cover of foliose lichens on rocks was much higher than cover values of lichens found on bark. This is difference consistent with other data indicating that bark lichens are more sensitive to air pollution than rock lichens (Bratt pers. comm. 1987, Sigal and Nash 1983). The ability of basic substrates to buffer the effect of pollution has been well documented (Ferry and Coppins 1979, Nieboer et al. 1979) and this cover difference may be the result of the more basic pH of the rock substrate.

CONCLUSION

In summary, lichens are sensitive indicators of air pollution impacts and thus are appropriate for use in monitoring the air quality related value of vegetation.

While lichens are good monitoring organisms, they are not as accurate as physical measurements. Used in conjunction with other types of monitoring, such as soil and water pH, visibility, physical ozone concentrations, etc., lichen monitoring can provide data necessary to fulfill the Federal Land Managers responsibilities under the Clean Air Act.

Lichens in the San Gabriel Wilderness have been impacted by air pollution. There has been a reduction in species diversity through a loss of sensitive species, there is a 17% infertility rate and morphological changes, and probable reduction in total percent cover of lichens. While lead concentrations are slightly higher than background concentrations, heavy metals have not had a large impact on the lichens of the San Gabriel Wilderness.

It can be inferred that air pollution has impacted air quality and air quality related values in the San Gabriel Wilderness. Sustained or increased pollution levels will continue to negatively impact this Class I Wilderness.

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APPENDIX A. Description of methods for surveying and monitoring the effect of air pollution on lichens.

Several methods of surveying lichen damage from pollution are cited in the literature. Included are floristic surveys, sensitive species mapping, chemical analysis of indigenous lichens, transplants, morphological comparisons and growth studies. These methods and their benefits and drawbacks are outlined below:

Floristic Surveys and Sensitive Species Mapping (Farkas, Lokos and Verseghy 1985; Gailey Smith, Rintoul and Lloyd 1985 Taylor and Bell 1983). This method is commonly used around a point source of pollution and is based on distribution diversity abundance and luxuriance of lichens. The easiest way to measure the effect of pollution is to compare the floristic composition of unpolluted sites with polluted sites of compare historical data with current data from the same site. In most places very little such data is available.

It is common to establish transects or sampling points at varying distances from the pollution source and document the factors listed above. Sensitive species are usually absent close to the point source, but will be present as one moves further away from the pollution source.

Drawbacks to this method include the excessive amount of time required to complete a thorough floristic inventory of an area the size of most Class I Wilderness Areas, not to mention the problem of the lack of access. In addition, this method is only good for common sensitive species because rare species may be absent for reasons other than pollution (Wetmore 1985).

Chemical Analysis of Indigenous Lichens (Addison and Puckett 1980, Fuchs and Garty 1983, Garty and Fuchs 1982, Lawry 1986, Pilegaard 1979). This method can give fairly precise levels of heavy metal content of lichen thalli. These levels can be compared with known background levels from other studies. Experts disagree as to whether one can compare lichens of similar growth form or whether you can only compare analyses from the same species. Rundel (pers. comm. 1987) indicated that morphologically similar species could be compared while Gailey et al. (1986a) found that there was too much variability for comparison between species. Drawbacks of this method include the fact that contamination from dust and substrate, differences in collection location and time of year and non-homogeneity of the samples can yield misleading results. In addition this method requires paying a laboratory to analyze the samples.

While the analyses are relatively inexpensive (approximately $10

per test), this analysis could become costly if many samples were analyzed.

Transplants [Ferry and Coppins 1979; Gailey, Smith, Rintoul and Lloyd 1985 (includes guidelines for selecting transplant material); Garty and Fuchs 1979; Kauppi 1976; Pilegaard 1979]. Lichens can be transplanted from areas known to have relatively clean air. Transplants may be bark plugs, branches or twigs. Changes in morphology or heavy metal content of the transplants can be monitored over time. Chemical analysis of transplants is preferred over analysis of naturally occurring lichens because you are able to eliminate variability that may arise from substrate and location differences (Nieboer et.al 1978, Pilegaard 1979). In addition transplants may be used in areas where sensitive species cannot be found in sufficient abundance. The best periods for transplanting are autumn and spring when humidities are high and lichen growth rates are at maximum (Sigal 1984). Concentration of heavy metal in transplants are dependent on exposure time, fallout and time of year (Pilegaard 1979). Pilegaard (1979) found that it takes approximately two months for heavy metal levels to achieve equilibrium.

Moss bags have been used successfully to monitor patterns and changes in heavy metal pollution (Brown 1984). They are simple and inexpensive to produce and are usually composed of nylon mesh bags filled with Sphagnum sp. Directions for producing moss bags can be found in Brown (1984), Hynninen (1986) and Little and Martin (1974).

Drawbacks to the transplant method include the unknown effect of possible changes in microclimate between collection and transplant locations, and the potential rapid death of transplants. Lichens transplanted into the Santa Monica Mountains died within six months (Bratt pers. comm. 1987) and lichens transplanted elsewhere died within one year (Hale 1983). Thus, specimens need to be checked frequently to monitor and document any possible decline. To minimize the effects of microclimate differences, transplants should be collected from sites similar to the transplant site in all respects except pollution levels. Other disadvantages to the transplant method are the fact that transplants do not sample for all heavy metals equally and they sample uncertain volumes of air.

Transects to Assess Percent Cover (DelMoral, Wood, VanHook, Clampitt 1984; Redwood National Park 1984, 1986; Sigal and Nash 1983). The amount of lichen cover and the species diversity are known to decrease in polluted areas. Transects can be used to monitor this decrease over time.

Drawbacks of this method include the large number of transects needed to determine the statistical validity of an apparent trend and the need for the presence of sufficient lichen

cover to monitor. In addition, this method is only good for showing large scale changes because sampling error is high. However, this method could be modified to increase accuracy and precision.

Morphological Comparisons (Sigal and Nash 1983). Lichens in polluted areas are known to have a reduction in the number of apothecia produced and an increase in the number of pycnidia. In addition the overall size of the thallus may decrease, lobe length may decrease and the thalli become may convoluted and bleached. Internally, algal cells and chloroplasts may become damaged, thus reducing the amount of chlorophyll present in the thallus.

Growth Studies. Growth or shrinkage rates of a lichen thallus can be monitored by tracing a thallus on acetate. This method is best suited for monitoring foliose lichens on rocks. This method can provide a fairly accurate record of changes in the thallus. Other morphological criteria such as number of apothecia per square cm, lobe length and degree of bleaching could be recorded at the same time.

APPENDIX B. Species list from Hasse's 1913 Lichen flora. Taxonomy is consistent with the Catalogue of California Lichens (1978).

SPECIES	COMMENTS
Acarospora chlorophana	Granite & Gneiss above 1600m.
A. pleiospora (Nyl.)	Type: along "New Trail" to Mt. Wilson.
Bacidia atrogrisea (Del.) Korb.	In canyons.
B. kingmanii Hasse	Quartzose rocks near Mt. Wilson, Ne Trail.
Bryoria oregana (Tuck. ex Nyl.) Brodo D.Hawksw.	On conifer bark and dead wood.
Buellia disciformes var. triphragmia (FR.) Mudd.	BCF & dead wood Mt. Wilson 1550 m.
B. penichra (Tuck.)	BCF Mt. Wilson 1500 m.
Calicium viride Pers.	On BCF San Gabriel Range.
Caloplaca trachyphylla (Tuck.) Zahlbr.	Crystalline rocks.
Collema leucocarpum Nyl.	On oak bark in canyons.
Dermatocarpon miniatum (L.)Mann	San Gabriel Mountains.
D. rufescens (Ach.) Zahlbr. in Engl. & Prantl	Near San Bernardino, on soil.
Dimalaena oreina (Ach.) Norm.	Quartzose rocks.
Dimalaena thysanota (Tuck.) Hal. & W.Culb.	Micaceous rocks.
Evernia prunastri (L.) Ach	Quite common in So. Calif.
Hypogymnia physodes (L.) Ach.	Sparingly on barks.
Lecanora chrysoleuca (Sm.) Ach.	Granitic rocks.
L. cinerea (L.) Somm.	Granite, 1700 m Mt. Wilson.
L. gibbosa (Ach.) Nyl.	San Gabriel Mountains.
L. glaucophanum Nyl.	Type: Camp Baldy 1600 m gneiss and granite, San Antonio Canyon.
L. laevata (Ach.) Nyl.	
L. subfusca (l.) Ach.	Smooth barks.
Lecania syringea Th. Fr.	Acer macrophyllum bark, canyon.
Lecidea atrobrunnea (Ramond)Schaer.	San Gabriel Canyon 1350 m.
L. atrolutescens (Mannii) Tuck.	Type: Mt. Wilson 1500-1600 m.
L. brandegei Tuck.	San Gabriels, 1500 m.
L. cinerata Zahlbr.	San Gabriel Mountains.
L. diducens Nyl.	Granite, San Gabriels.
L. fuscoatra (L.) Ach.	Granite, San Gabriels.
L. globifera Ach.	
L. glomerulosa (DC) Steud.	On California bay laurel.
L. lapicida (Ach.) Ach.	Granite, other hard crystalline rock.

APPENDIX B. Continued.

SPECIES	COMMENTS
L. protobacina Nyl.	Type: Mt. San Antonio 3300 m.
L. vorticosa (Florke) Koerbe	Desert side of S. Gabriels, decomposed granite.
L. elabens Th. Fr.	BCF bark, 1600 m.
Lecidella goniophila (Floerke) Schaer.	Shoemakers Ranch, San Gabriels.
L. vernalis (L.) Ach.	Decorticated pine, San Gabriels.
Leptochidium albociliatum (Desm.)	On soil, foothills.
Letharia vulpina (L.) Hue	
Massalongia microphylliza (Nyl.)	Type: Old Wilson Trail on quartz.
Melanelia glabra (Schaer.) Essl.	
Micarea viridescens (Schrad.) Brodo	On barks, San Antonio Canyon.
Omphalodiscus virginis (Schaer.) Schol.	BCF, San Gabriels.
Parmelia cylisphora (Ach.) Wain	Granite, 3500 m on Mt. San Antonio.
P. multispora A. Schneid.	Boulders, dead and living bark.
P. perlata (Huds.) Ach.	On shrubs, not infrequent.
P. saxatilis (L.) Ach.	On trunks.
Parmelina quercina (Willd.) Hale	On moss covered rocks & tree bases 1600 m.
Peltigera canina (L.) Willd.	On barks.
P. c. sorediata (Schaer.) Fink.	On earth and rocks among mosses.
Peltula polyspora (Tuck.) Wetm.	On earth and rocks among mosses.
P. zahlbruckneri (Hasse) Wetm.	Type: New Trail to Mt. Wilson 650 m
Phlyctis agelaea (Ach.) Flot.	Type: On quartz, Rubio Canyon.
P. argena (Ach.) Flot.	Acer macrophyllum.
P. stellaris (L.) Nyl.	In canyons on bark.
Physconia pulverulenta (Hoffm.) Leight	Frequent, stones, bark, dead wood t 2000 m.
P. p. angustata	Earth and rocks.
P. grisea (Ach.) Nyl.	Smooth oak bark along New Trail to Mt. Wilson 800 m.
Pseudocyphellaria anthraspis (Ach.) Magn.	Wood and mossy rocks.
	On oak bark, New Mt. Wilson Trail.

SPECIES	COMMENTS
Ramalina menziesii Tayl.	Frequent on shrubs ascending mts. t 800 m So. Calif.
Rhizocarpon bolanderi (Tuck.) Herre	San Gabriels.
Rinodina hallii Tuck.	On oaks @ & above 800 m.
R. sophodes Nyl.	BCF from 1000 and up.
Sarcogyne californica Magn.	Various rocks.
Toninia squalida persimilans Nyl.	On earth, 830 m Old Wilson Trail.
Umbilicaria angulata Tuck.	On boulders, 1500 m Camp Baldy.
Usnea filipendula Nyl.	On shrubs.
Usnea scabrata Nyl.	On shrubs.
Xanthoparmelia subconspersa (Nyl.) Hale	On boulders.

APPENDIX C. Inferred sensitivity of selected lichen species to air pollution in the southern California mountains from Sigal and Nash, 1983.

VERY SENSITIVE	SENSITIVE
Bryoria abbreviata	Cetraria merrillii
Bryoria cf. fremontii	Collema nigrescens
Cetraria canadensis	Leptogium californicum
Evernia prunastri	Parmelia sulcata
Peltigera canina	P. quercina
P. collina	Peltigera rufescens
P. spuria	Physcia ciliata
Physcia sciastra	P. orbicularis
Platismatia glauca	Polychidium albociliatum
Pseudocyphellaria anthraspis	Usnea sp.
Ramalina farinaceae	
R. menziesii	
Xanthoria candelaria	

MODERATELY TOLERANT	TOLERANT
Hypogymnia enteromorpha	Letharia vulpina
Parmelia glabra	Physcia biziana group
P. elegantula	P. tenella
P. subolivacea	Physconia grisea
Xanthoria polycarpa	Xanthoria fallax

APPENDIX D. Species collected in Sequoia National Park and their sensitivity to sulfur dioxide from Wetmore (1985).

SPECIES	SENSITIVITY
Buellia punctata	Tolerant
Calicium viride	Intermediate
Caloplaca cerina	Sensitive-Intermediate
Candelaria concolor	Sensitive-Intermediate
Candelariella vitellina	Intermediate
Cladonia coniocraea	Intermediate
C. fimbriata	Sensitive Intermediate
Evernia prunastri	Intermediate
Lecanora carpinea	Intermediate
L. chlarotera	Intermediate
L. muralis	Tolerant
L. saligna	Intermediate
Lecidea scalaris	Intermediate
Lecidella elaeochroma	Intermediate
Normandina pulchella	Sensitive-Intermediate
Ochrolechia androgyna	Sensitive
Parmelia saxatilis	Intermediate
P. subargentifera	Intermediate-Tolerant
P subaurifera	Sensitive
P. sulcata	Intermediate-Tolerant
Parmeliopsis ambigua	Intermediate
Physcia adscendens	Intermediate
P. aipolia	Intermediate
P. dubia	Tolerant
P. stellaris	Intermediate
P. tenella	Intermediate
P. detersa	Intermediate
P. distorta	Intermediate
Platismatia glauca	Intermediate
Ramalina farinacea	Sensitive
Rinodina exigua	Intermediate
Xanthoria candelaria	Intermediate
X. fallax	Sensitive-Intermediate
X. polycarpa	Intermediate

APPENDIX E. Chemical analysis results received from the Laboratory of Biomedical and Environmental Sciences at University of California at Los Angeles.

CONCENTRATION IN DRY TISSUE — ANGELES NATIONAL FOREST LICHENS DR. COPENHAGEN — VALUES ARE % OR PPM (1% = 10,000PPM) — 072187.C13:2

	WEIGHT	1 P	2 NA	3 K	4 CA	5 MG	6 ZN	7 CU	8 FE	9 MN	10 B
SG-2 01	8.1	0	403	9110	1010	1090	50.7	14.6	1130	93.0	2.65
SG-2 02	7.8	0	560	7410	695	1070	52.7	18.0	1630	85.7	3.08
SG-2 03	8.8	668	408	7460	657	764	52.6	11.3	771	57.9	2.68
SG-29 01	7.3	203	292	6450	523	644	18.7	6.85	593	50.3	3.46
SG-29 02	8.2	0	728	7960	792	1190	33.2	8.82	2540	108	4.61
SG-29 03	7.4	463	306	4290	434	811	20.7	8.09	706	62.6	4.67
SG-33 01	7.9	0	1720	1.34%	3560	2350	47.2	14.2	2870	223	2.77
SG-33 02	8.3	3340	721	6800	2.31%	1510	31.9	9.05	1380	148	1.92
SG-33 03	8.8	0	870	8120	2.45%	1550	32.4	7.35	2490	161	1.14
SG-36 01	7.8	0	2090	1.56%	1730	2870	86.5	25.8	3120	323	3.04
SG-36 02	7.2	0	2890	1.73%	2870	3330	89.4	27.1	3330	355	4.41
SG-36 03	7.9	0	1970	1.39%	1760	3020	80.1	24.4	3700	317	3.48
SG-37 01	7.8	825	87.0	2930	351	380	15.7	3.52	155	47.0	1.43
SG-37 02	8.2	0	240	1.37%	1820	756	20.6	5.27	1200	73.0	2.06
SG-37 03	8.9	0	158	5550	801	583	20.6	6.13	579	61.8	1.40
SG-38 01	8.1	0	1250	8600	1.16%	1370	31.0	10.6	1870	138	3.17
SG-38 02	7.4	0	1540	1.10%	1.25%	1470	16.3	7.27	3230	134	3.63
SG-38 03	7.4	0	1740	1.42%	1.32%	1920	41.5	9.71	1950	222	2.47
SG-51 01	7.4	1530	312	8720	4350	1020	16.8	3.26	600	92.6	2.16
SG-51 02	7.3	542	250	8330	4880	935	23.6	5.51	735	112	3.04
SG-51 03	7.4	1400	370	6160	1690	1330	19.6	5.64	534	84.6	1.49
UPPER LIMIT		10.0%	20.0%	20.0%	20.0%	5.00%	10.0%	1000	1.50%	5.00%	3000
LOWER LIMIT		50.0	1.00	150	1.00	50.0	5.00	0.20	0.60	0.10	1.00

	WEIGHT	11 AL	12 SI	13 TI	14 V	15 CO	16 NI	17 MO	18 CR	19 SR	20 BA
SG-2 01	8.1	753	3600	14.4	0	0.26	0.22	0.59	0	10.6	18.6
SG-2 02	7.8	964	5500	25.5	0	0.21	1.14	1.26	2.95	9.11	29.4
SG-2 03	8.8	479	2770	15.3	0	0	0.93	0.25	0.45	9.71	18.4
SG-29 01	7.3	662	2860	10.6	0	0.59	0	0.40	0	9.19	16.4
SG-29 02	8.2	1230	6860	32.3	0.37	0.81	0.81	1.26	0	16.2	31.2
SG-29 03	7.4	655	5300	19.6	0	0.46	0.42	0.74	0.17	6.22	17.3
SG-33 01	7.9	1910	9050	57.4	2.90	0.98	1.98	1.52	5.24	34.4	57.8
SG-33 02	8.3	1670	5960	63.9	0.81	0.42	1.22	0.92	3.74	57.6	35.7
SG-33 03	8.8	2330	7500	54.0	1.52	0.46	0.82	0.61	1.23	66.9	36.7
SG-36 01	7.8	2280	1.07%	93.2	4.01	0.81	2.47	2.24	8.99	32.6	75.6
SG-36 02	7.2	2600	1.17%	91.4	6.92	0.92	2.46	2.00	5.89	32.6	67.0
SG-36 03	7.9	1970	1.19%	101	4.44	1.00	2.60	2.41	9.47	25.2	68.2
SG-37 01	7.8	156	1160	3.27	0	0	0	0.07	1.78	1.91	4.44
SG-37 02	8.2	760	3650	10.5	0	0.41	0	0.06	0	16.1	16.0
SG-37 03	8.9	336	1950	4.69	0	0.24	0.85	0.18	3.26	9.15	10.4
SG-38 01	8.1	1960	8640	54.7	0	0.51	1.00	0.83	2.05	24.3	41.2
SG-38 02	7.4	2240	8430	88.6	0.32	1.20	0.87	2.00	0	22.3	43.8
SG-38 03	7.4	2280	9210	59.4	0	0.84	0.39	1.35	0	28.0	43.4
SG-51 01	7.4	694	2990	18.1	0	0.33	0.18	0	0	26.8	39.1
SG-51 02	7.3	512	2730	18.4	0	0.27	0.63	0.07	2.61	24.3	33.0
SG-51 03	7.4	641	3130	15.3	0	0.48	1.21	0.63	0.95	17.3	37.1
UPPER LIMIT		3.00%	10.0%	2.00%	500	2000	2000	2000	300	1000	2000
LOWER LIMIT		1.00	1.00	0.50	1.00	1.50	0.50	0.20	0.20	0.20	0.20

	WEIGHT	21 LI	22 AG	23 SN	24 PB	25 BE	26 CD	27 AS
SG-2 01	8.1	1.44	0.04	0.37	114	0	0.89	0
SG-2 02	7.8	2.35	0.02	0.23	80.7	0	1.05	0
SG-2 03	8.8	0	0	0.15	68.0	0	1.30	0
SG-29 01	7.3	2.03	0.00	0.28	26.6	0	0.04	0
SG-29 02	8.2	2.22	0.03	0.40	27.3	0	0.58	0
SG-29 03	7.4	2.87	0.02	0	31.7	0	0.34	0
SG-33 01	7.9	2.83	0.02	0	27.7	0	0.80	0
SG-33 02	8.3	3.70	0	0	79.9	0	2.07	0
SG-33 03	8.8	2.25	0	0	64.5	0	2.66	0
SG-36 01	7.8	3.01	0.06	0	38.5	0	1.39	0
SG-36 02	7.2	2.74	0.03	0.16	65.2	0	1.13	0
SG-36 03	7.9	2.95	0.06	0	46.9	0	0.79	0
SG-37 01	7.8	1.80	0	0.23	7.65	0	0	0
SG-37 02	8.2	0	0	0	2.99	0	0	0
SG-37 03	8.9	0.57	0.01	0.04	13.2	0	0.33	0
SG-38 01	8.1	2.92	0.01	0	45.5	0	1.18	0
SG-38 02	7.4	2.39	0	1.85	31.8	0	0	0
SG-38 03	7.4	2.80	0	0	44.2	0	0.74	0
SG-51 01	7.4	0	0	0.15	37.4	0	0	0
SG-51 02	7.3	0.61	0.01	0	42.3	0	0	0
SG-51 03	7.4	2.16	0	0.20	31.0	0	0.03	0
UPPER LIMIT		2000	100	100	3000	1.00%	1.10%	1.00%
LOWER LIMIT		0.30	0.10	0.30	1.00	0.20	3.00	1.00

APPENDIX F. Elemental contents of lichens from both unpolluted and polluted areas as found in the literature.

1. Addison and Puckett 1980. Content of pollutants in Hypogymnia physodes around the Athabasca Oil Sands area in Canada. Measurements are in micrograms/gram.

ELEMENT	CONCENTRATION
Aluminum	2000-5000
Sulfur	1000-2500
Vanadium	100- 250

2. Gailey, Smith, Rintoul and Lloyd 1985. Mean concentration of elements in unexposed lichens. Measurements are in ppm/dry weight.

ELEMENT	CONCENTRATION
Iron	849.6
Manganese	203.1
Zinc	106.4
Lead	5.2
Copper	11.4
Nickel	2.8

3. Nieboer et al. 1978. Review article, no species given. Measurements are in micrograms/gram.

ELEMENT	BACKGROUND CONCENTRATION	ENHANCED CONCENTRATION
Nitrogen	6000-50,00	
Sodium	50-1000	100-6000
Magnesium	100-1000	1000-12000
Aluminum	300-400	1300-1900
Phosphorous	200-2000	
Silicon	50-2000	2000-13000
Potassium	500-5000	5000-9500
Calcium	200-40,00	40000-55000
Titanium	6-150	150-3800
Vanadium	0-10	10-300
Chromium	0-10	25-130
Manganese	10-130	300-5000
Iron	50-1600	400-90000
Nickel	0-5	10-300
Copper	1-50	15-1100
Zinc	20-500	1000-25000
Strontium	0-700	
Molybdenum	0-3	1-10
Cadmium	1-30	30-330
Mercury	0-1	
Lead	20-100	100-12000

4. DeBruin and Hackenitz 1986. Pollutant concentrations in *Parmelia sulcata* from an area in the Netherlands that has been polluted for more than a century. Units are in ppm.

POLLUTANT	AVERAGE CONCENTRATION	RANGE
Sodium	630	340-1100
Aluminum	4100	1100-7300
Potassium	5400	4300-7500
Calcium	2900	1400-5100
Scandium	0.89	0.38-1.55
Vanadium	25	9.0-48
Chromium	18	8.8-38
Manganese	75	55-150
Iron	3700	2000-6400
Cobalt	2.4	0.70-402
Copper	36	13-55
Zinc	590	24-1500
Arsenic	8.3	108-14
Bromine	34	24-48
Cadmium	3.9	0.92-6.3
Antimony	3.7	1.2-6.3
Barium	57	32-2000
Lanthanum	3.5	1.5-6.1
Hafnium	1.5	.32-3.0
Tungsten	0.72	.22-1.5

APPENDIX G. Additional related references not cited in the text.

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